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Dated this 12th day of April, 2005

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SPECIFICATION

POLYIMIDE BLOCK COPOLYMER SOLUTION COMPOSITIONS
CONTAINING PYROMELLITIC DIANHYDRIDE AND
PROCESSES FOR THE PREPARATION THEREOF

5 FIELD OF THE INVENTION

The present invention relates to solvent-soluble polyimides containing pyromellitic dianhydride, or solvent-soluble polyimides containing pyromellitic dianhydride, benzophenonetetracarboxylic dianhydride and diaminotoluene. 10 More specifically, it relates to four-component or higher polyimide block copolymer solution compositions obtained by polycondensation, especially sequential polymerization reactions under the action of an acid catalyst in a polar solvent, and processes for the preparation thereof.

15

PRIOR ART

Polyimides are known as a class of materials resistant to high temperatures for a long period, and are widely used as electric/electronic components in the 20 aerospace industry and other fields because of their high electric insulation, mechanical strength and chemical resistance. Especially in the current semiconductor industry, they are essential materials.

Various polyimides are currently known, among which 25 polyimides consisting of pyromellitic dianhydride (hereinafter referred to as PMDA) and 4,4'-diaminodiphenyl ether (hereinafter referred to as DADE) are well-known as the first commercialized polyimides.

It is known that aromatic polyimides are normally solvent-insoluble and that polyimides based on PMDA especially have low solubility in solvents. Thus, conventional processes for synthesizing polyimides typically involve reacting PMDA and DADE in a polar solvent such as N-methylpyrrolidone or N,N-dimethylacetamide at a low temperature to synthesize a polyamic acid (polyimide precursor), which is a polycondensation product having a high molecular weight and a high viscosity, and heating it at 250-350°C to give a polyimide via dehydration and ring-closing reactions (See Polyimide; D. Wilson, H. D. Steinberger, P. M. Morgenrother; Blackie (New York) 1990).

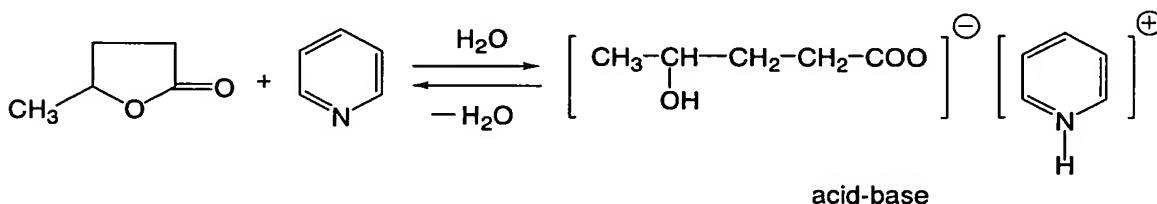
Polyamic acids are unstable to heat in solutions and readily decompose in water. Thus, they have poor storage stability and should be frozen-stored. Polyamic acids undergo rapid intermolecular interactions in polar solvents, and even attempts to modify their behavior by adding other components have little effect and result in random copolymers. Polyamic acids undergo changes even at room temperature, so that the molecular weight measurements by GPC are not reproducible. Thus, polyamic acids are identified by measuring their intrinsic viscosities instead of molecular weights.

Solvent-soluble polyimides can be directly prepared by imidation reactions in solutions without the intermediation of polyamic acids. Imidation is carried out by heating at 160-200°C in the presence of an acid catalyst such as sulfuric acid or P-toluenesulfonic acid. After

completion of the reaction, the acid catalyst remaining in the polyimide solution may cause deterioration of the polymer product. Therefore, the polyimide should be separated from the catalyst by precipitating out the polyimide and redissolving it.

Processes of the present invention use acid-base catalysts based on the equilibrium of lactone to promote dehydration-imidation reactions.

The binary catalyst systems consisting of γ -valerolactone and pyridine and/or N-methylmorpholine described in the specification of US Patent No. 5502143 can be used. As imidation proceeds, water is produced and contributes to the equilibrium of lactone to form an acid-base system showing a catalytic effect.



The water produced by imidation is removed from the reaction medium by azeotropic distillation with toluene or xylene coexisting with the polar solvent. When the reaction is completed, the solution is free from water and the acid-base system returns to γ -valerolactone and pyridine to give a high-purity polyimide solution from which water has been removed by azeotropic distillation with toluene or xylene.

Polyimides containing PMDA are normally solvent-insoluble. An object of the present invention is to allow them to be solubilized in solvents, thereby producing four-component or higher solvent-soluble block copolymers.

5 Solvent-soluble polyimides can be formed into multicomponent polyimide block copolymer solutions using sequential reactions.

DISCLOSURE OF THE INVENTION

10 An aspect of the present invention relates to four-component or higher polyimide block copolymer solution compositions containing pyromellitic dianhydride (hereinafter referred to as PMDA) and processes for the preparation thereof.

15 Another aspect of the present invention relates to polyimide block copolymer solution compositions containing pyromellitic dianhydride, benzophenonetetracarboxylic dianhydride (hereinafter referred to as BTDA) and diaminotoluene (hereinafter referred to as DAT) and
20 processes for the preparation thereof.

PREFERRED EMBODIMENTS OF THE INVENTION

Polyimides that are soluble in polar solvents such as N-methylpyrrolidone and N,N-dimethylacetamide are known.
25 The solubilities of polyimides vary with the characteristics, compositions and combinations of acid dianhydrides and aromatic diamines.

The solvent solubilities of polyimide are discussed

below. It is known that aliphatic polyimides are more readily soluble than aromatic polyimides and that fluorine-containing polyimides are also readily soluble in solvents.

The solubilities of polyimides containing acid dianhydrides decrease in the following order:

BCD>6FDA>>BTDA>BPDA>>PMDA

(BCD: bicyclo(2,2,2)-oct-7-ene-2,3,5,6-tetracarboxylic dianhydride,

6FDA: 2,2-bis (3,4-dicarboxyphenyl)-1,1,1,3,3,3-hexafluoropropane dianhydride,

BTDA: 3,4,3',4'-benzophenonetetracarboxylic dianhydride,

BPDA: 3,4,3',4'-biphenyltetracarboxylic dianhydride.)

The solubilities of polyimides containing these acid dianhydrides decrease in this order. Especially, polyimides containing PMDA have low solubilities.

In view of the solubilities of different acid dianhydrides, polyimides containing PMDA showing the solubilities of aromatic polyimides are the most insoluble. Polyimides containing combinations of PMDA and BTDA can be formed into relatively large numbers of solvent soluble block polyimides by synthesizing the polyimides with certain types of diamines in appropriate ratios.

A document "Modern polyimides", by Imai and Yokota (eds.), NTS (2002) pp. 143-153 describes model molecules calculated by a molecular orbital method based on density functional theory (DFT) as a guideline for evaluating the solubilities of polyimides. The order of the electron-

accepting ability of acid dianhydrides calculated by DFT, and the order of the electron-donating ability of diamines calculated by DFT, is shown.

PMDA has high electron-accepting ability.

- 5 Evaluations of the electron-donating ability, steric bulk and steric strain of aromatic diamines are useful for selecting soluble polyimides.

Solvents that can be used in the preparation of polyimides include N-methylpyrrolidone, N-methylformamide, 10 N,N-dimethylformamide, N-methylacetamide, N,N-dimethylacetamide, tetramethylurea, dimethyl sulfoxide, and sulfolane. The amount of polyimides to be dissolved in these solvents is 10% by weight or more, preferably 15-25% by weight.

- 15 A hydrocarbon such as toluene or xylene is added to the polar solvents listed above.

The imidation reaction is promoted while removing the water produced during the reaction from the reaction medium by azeotropic distillation with the hydrocarbon.

- 20 One mole of PMDA and 2 moles of an aromatic diamine were added at a concentration of 15% by weight in an N-methylpyrrolidone solution (hereinafter referred to as NMP) and heated at 170-180°C or 170-175°C in the presence of an acid catalyst to form an imide oligomer. When the imide 25 oligomer precipitates, the diamine can be selected from the list shown below.

List 1

1,4-diaminobenzene, 1,3-diaminobenzene, 3,5-

diaminobenzoic acid, 2,4-diamino-1-methyl-S-triazine,
4,4'-diamino-3,3'-dimethylbiphenyl, 4,4'-diamino-3,3'-
dimethoxybiphenyl, 4,4'-diamino-3,3'-dimethyldiphenyl
sulfone, 1,5-diaminonaphthalene, 2,4-diaminophenol, 4,4'-
5 diamino-3,3'-dihydroxybiphenyl, 3,4'-diaminodiphenyl ether,
4,4'-diaminodiphenyl ether, 4,4'-diaminodiphenyl methane,
4,4'-diaminodiphenyl sulfide, 4,4'-diaminodiphenyl sulfone,
4,4'-diaminobenzamide, bis (4-aminophenoxy)-1,4-benzene,
2,2-bis (4-(4-aminophenoxy)phenyl)propane, 2,2-bis (4-(4-
10 aminophenoxy)phenyl)hexafluoropropane, 4,4'-bis (4-
aminophenoxy)diphenyl sulfone, 3,3'-diethyl-4,4'-
diaminodiphenyl methane, and 4,4'-[1,4-phenylene-bis
(1-methylethylidene)]bisaniline.

One mole of PMDA and 2 moles of an aromatic diamine
15 were added at a concentration of 15% by weight in NMP and
heated at 170-175°C in the presence of an acid catalyst.
When the resulting polyimide oligomer is solubilized in the
solution, the aromatic diamine can be selected from the
list shown below.

20 List 2

2,4-diaminotoluene, bis- (3-aminophenoxy)-1,3-benzene,
bis[(3-aminophenoxy)-1,4-phenyl] sulfone, 3,3'-
diaminodiphenyl sulfone, 2,2-bis[3-amino-4-phenoxyphenyl]-
hexafluoropropane, bis[3-amino-4-phenoxyphenyl] sulfone,
25 9,9-bis (4-aminophenyl)fluorene, 3,5-diaminobenzoic acid,
and 4,4'-diamino-3,3'-dioxycarbonyl-diphenylmethane.

Compounds in List 1 produce insoluble polyimides via
reactions with PMDA. List 2 shows diamine components

producing soluble polyimides.

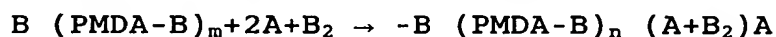
In the light of these facts, processes for preparing soluble polyimide block copolymers containing PMDA were searched.

5 A first process is shown below.

In the reaction of the first step, 1.5-2 moles of an aromatic diamine (B_1) shown in List 2 per mole of PMDA is added, and the mixture is heated at 160-180°C in the presence of an acid catalyst to produce an oligomer
10 terminated with diamines at both ends.

$$\text{PMDA} + B \rightarrow B (\text{PMDA}-B)_m \quad \text{wherein } m=1 \text{ or } 2 \text{ in most cases.}$$

In the reaction of the second step, another acid dianhydride (A) and another diamine B_2 and/or B_3 are reacted
15 to give a polyimide block copolymer solution.



wherein the molar ratio between the total acid dianhydrides and the total aromatic diamines is 1:1-0.95
20 i.e. the molar ratio of the total aromatic diamines to the total acid dianhydrides is 1-0.95.

The acid dianhydride used in the second step can be 6FDA, BTDA, BPDA, 3,4-dicarboxyphenyl sulfone anhydride, bis (3,4-dicarboxyphenyl) ether anhydride, 2,3,6,7-naphthalenetetracarboxylic anhydride, etc.
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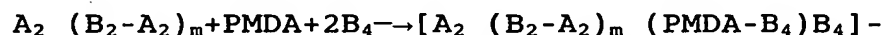
The aromatic diamine used in the second step in the present invention can be selected from the diamines shown in List 1 and List 2.

Another process for preparing a polyimide block copolymer is shown below. In the reaction of the first step, an acid dianhydride other than PMDA (A_2) and an aromatic diamine (B_2) are reacted. The molar ratio between
 5 A_2 and B_2 is 2:1. An oligomer terminated with acid dianhydrides at both ends is produced.



The acid dianhydride used as A_2 can be 6FDA, BTDA, BPDA, 3,4-dicarboxyphenyl sulfone anhydride, bis
 10 (3,4-dicarboxyphenyl) ether anhydride, 2,3,6,7-naphthalenetetracarboxylic anhydride, etc., and B_2 can be selected from List 1 and List 2.

In the reaction of the second step, PMDA and an aromatic diamine (B_4) are added. B_4 can be selected from
 15 List 1 and List 2. However, the B_4 /PMDA molar ratio is 2-1.5/1.0.



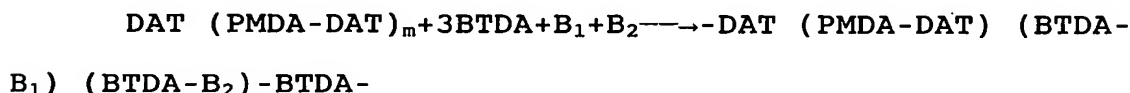
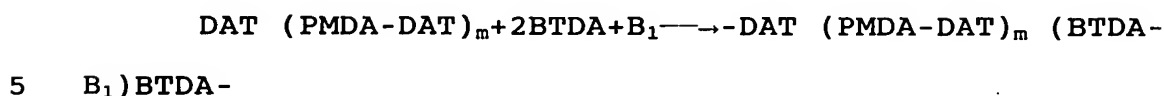
The molar ratio between the total aromatic acid
 20 dianhydrides and the total aromatic diamines is 1:1-0.95, i.e. the molar ratio of the total aromatic diamines to the total aromatic acid dianhydrides is 1-0.95.

Still another process for preparing a polyimide block copolymer is shown below.

25 In the reaction of the first step, PMDA (1 mole) and diaminotoluene (DAT) (2-1.5 moles) are added to produce an oligomer terminated with diamines at both ends.



In the reaction of the second step, BTDA and other diamines (B_1 , B_2) are added to carry out an imidation reaction.



The molar ratio between the total acid dianhydrides and the total aromatic diamines is 1:1.00-0.95, i.e. the molar ratio of the total aromatic diamines to the total acid dianhydrides is 1.00-0.95, and B_1 and B_2 can be selected from List 1 and List 2.

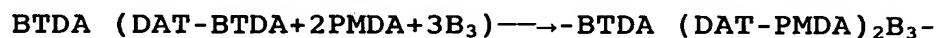
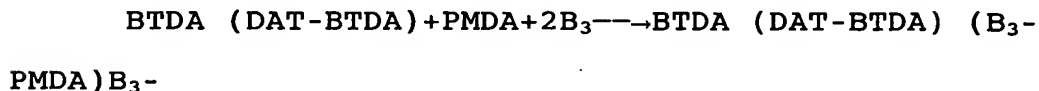
In yet another synthesis process, BTDA and DAT can be used in the reaction of the first step.



An oligomer terminated with acid dianhydrides at both ends is produced.

In the reaction of the second step, PMDA and diamine B_3 are added to carry out an imidation reaction.

The molar ratio of diamine B_3 to PMDA is 1:1.5-2.0.



The molar ratio between the total dianhydrides and the total aromatic diamines is 1:1-0.95, i.e. the molar ratio of the total aromatic diamines to the total dianhydrides is 1-0.95.

Aromatic diamines used in place of DAT in (2BTDA+DAT)

are shown below.

List 3

- 4,4-diaminodiphenyl sulfide,
- bis[4- (3-aminophenoxy)phenyl]sulfone,
- 5 bis[4- (4-aminophenoxy)phenyl]sulfone,
- 2,2-bis[4- (4-aminophenoxy)phenyl]propane,
- 2,2-bis[4- (4-aminophenoxy)phenyl]hexafluoropropane,
- 9,9-bis (4-aminophenoxy)fluorene,
- 1,3-bis (3-aminophenoxy)benzene,
- 10 2,4-diaminophenol.

The aromatic diamine used in combination with PMDA in the second step can be selected from List 1 and List 2.

- Polyimide block copolymer solutions containing PMDA, and polyimide block copolymer solutions containing PMDA, 15 BTDA and DAT, are stable at room temperature and do not readily decompose even when water is added. Thus, the polyimides are readily reproducible with a precision of $\pm 10\%$ based on the molecular weights and molecular weight distributions determined by GPC.

- 20 These polyimide block copolymer solutions produce characteristic polyimides depending on their schemes and types. They can be used as polyimide films, insulating varnishes, electroplating polyimides, photosensitive polyimides, sealants, adhesives, etc. Polyimides prepared 25 from inexpensively and readily available materials are provided at low production costs.

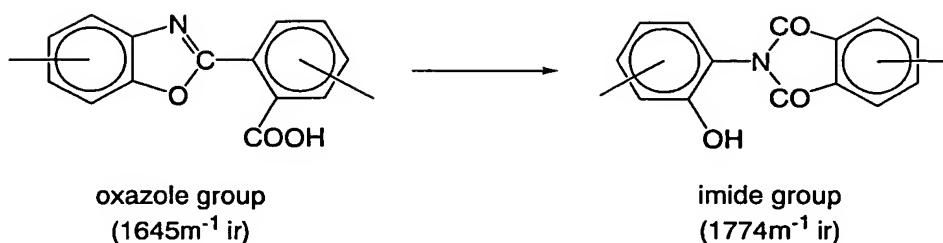
Condensation products of an aromatic diamine having an amino group and a hydroxy group in the ortho positions

with an aromatic tetracarboxylic dianhydride do not consist of only hydroxypolyimide groups. In this case, polycondensation products containing imide group components and benzoxazole group components in their molecules are
5 produced.

Condensation products having imide groups and benzoxazole groups are effective as positive photoresists. The benzoxazole groups readily decompose to form positive images by exposure to light in the presence of a photoacid
10 generator and development in an alkaline solution.

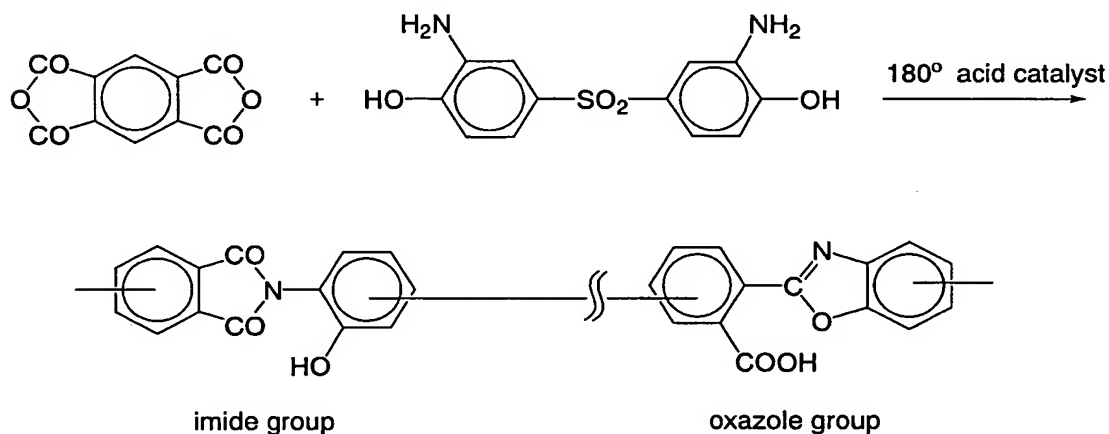
Aromatic diamines having an amino group and a phenolic hydroxyl group in ortho position to each other include 1-hydroxy-2,4-diaminobenzene, 1-hydroxy-2,5-diaminobenzene, 3,3'-dihydroxybenzidine, 3,3'-dihydroxy-
15 4,4'-diaminodiphenyl ether, 1,4-bis (3-hydroxy-4-aminophenoxy)benzene, 2,2-bis (4-amino-3-hydroxyphenyl)propane, bis (3-amino-4-hydroxyphenyl)propane, bis (3-amino-4-hydroxyphenyl) sulfide, bis (3-amino-4-hydroxyphenyl)sulfone, and 2,2'-bis (3-amino-4-
20 hydroxyphenyl)hexafluoropropane. These aromatic diamines can be used alone or in combination.

The polycondensation products containing imide groups and benzoxazole groups are cast and heated at 90°C to form a film. When this film is heat-treated at 300-350°C, the
25 benzoxazole groups are converted into imide groups to form a wholly aromatic polyimide.



A process for forming a positive image is described below.

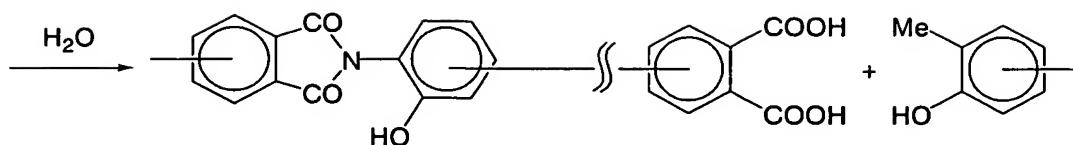
- 5 I. PMDA and 3,3'-diamino-4,4'-dihydroxydiphenyl sulfone are heated at 160-200°C in the presence of an acid catalyst in an NMP solution to produce a polycondensation product having imide groups and benzoxazole groups in the molecule.



10

- 15 II. The polycondensation product is prebaked in the presence of a photoacid generator and then exposed to light through a resist film, whereby the oxazole groups are readily excited.

 III. The benzoxazole groups decompose to form a positive image by development in an alkaline solution.



The following examples further illustrate the present invention. However, the present invention is not solely
 5 limited to these examples, since various characteristic polycondensation products are obtained by combining various acid dianhydrides and aromatic diamines.

[Example 1]

10 A 3-neck separable glass flask fitted with a stainless steel anchor stirrer was connected to a condenser tube equipped with balls and a water trap. The flask was heated in a silicone oil bath and stirred under a stream of nitrogen gas.

15 The 3-neck flask was charged with 17.45 g (80 mmol) of pyromellitic dianhydride (hereinafter referred to as PMDA), 14.66 g (120 mmol) of 2,4-diaminotoluene (hereinafter referred to as DAT), 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, 212 g of
 20 N-methylpyrrolidone (hereinafter referred to as NMP), and 30 g of toluene, and heated in a silicone bath at a temperature of 180°C for 1 hour with stirring at 180 r.p.m. under a stream of nitrogen gas. A 20 ml water-toluene fraction was removed. The flask was allowed to cool for
 25 1 hour with stirring. Then, 8.01 g (40 mmol) of 3,4'-diaminodiphenyl ether and then 23.54 g (80 mmol) of

3,4,3',4'-biphenyltetracarboxylic dianhydride were added. Then, 100 g of NMP and 10 g of toluene were added. After stirring at room temperature for 30 minutes, the reaction vessel was heated in a silicone oil bath at 180°C with
5 stirring at 180 r.p.m. under a stream of nitrogen gas. The reaction was continued for 3 hours to give a 20% by weight polyimide solution.

A part of the reaction solution was applied on a glass plate and dried by heating in an infrared oven at
10 90°C to give a strong film.

A part of the reaction solution was diluted with dimethylformamide and the molecular weight and molecular weight distribution were determined by high speed liquid chromatography (available from Tosoh Corporation). The
15 molecular weight measurements based on polystyrene standards showed peak molecular weight (M) 52,000, number average molecular weight (Mn) 23,400, and weight average molecular weight (Mz) 365,800, resulting in a single curve with $M_w/M_n = 3.12$, $M_z/M_n = 15.7$. Thermal analysis was
20 performed using a thermal analyzer TGA-50 and a differential scanning calorimeter (DSC) available from Shimadzu Corporation. Thermal decomposition onset temperature T_m was 528°C and the temperature at which a 5% weight loss was observed was 504°C, while T_g was unknown by
25 DSC.

[Example 2]

A solution of a polycondensation product was prepared

by the procedure described in Example 1A flask was charged with 5.46 g (25 mmol) of PMDA, 17.43 g (50 mmol) of 9,9-bis(4-aminophenyl)fluorene, 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, 20 g of NMP, and 30 g of toluene. The flask was heated in a silicone bath at a temperature of 180°C for 1 hour at 180rpm. The silicone bath was removed and the reaction solution was allowed to cool for 1 hour, and then 12.97 g (25 mmol) of 2,2-bis[4-(4-aminophenoxy)phenyl]hexafluoropropane and 9.11 g (25 mmol) of 2,2-bis[4-(3-amino-4-hydroxyphenyl)]hexafluoropropane were added, followed by 33.32 g (75 mmol) of 2,2-bis(3,4-dicarboxyphenyl)1,1,1,3,3,3-hexafluoropropane dianhydride, 100 g of NMP, and 10 g of toluene. The flask was heated in a silicone oil bath at 180°C for 4 hours with stirring at 160 rpm. A 25% by weight polyimide solution was produced. The reaction solution was cast on a glass plate and dried at 90°C to give a strong film.

The molecular weight and molecular weight distribution were determined by GPC. The results showed M_w 92,700, M_n 32,800, M_w 101,800, M_z 207,900, $M_w/M_n = 3.15$, and $M_z/M_n = 6.44$.

Thermal analysis was performed. T_m was 518°C, and the temperature at which a 5% weight loss was observed was 459°C, while T_g was unknown by DSC.

The IR spectrum showed absorption bands at 1780 cm^{-1} (absorption by imide bond), 1720 cm^{-1} (absorption by carbonyl), and 1645 cm^{-1} (absorption by oxazole).

[Example 3]

A solution of a polycondensation product was prepared by the procedure as described in Example 1.

A flask was charged with 8.73 g (40 mmol) of PMDA,
5 9.78 g (80 mmol) of DAT, 1.0 g (10 mmol) of γ -valerolactone,
1.6 g (20 mmol) of pyridine, 148 g of NMP, and 30 g of
toluene.

After the mixture was reacted at 180°C for 1 hour at
160 rpm, the reaction solution was allowed to cool. After
10 1 hour, 8.50 g (40 mmol) of 3,3'-dimethylbenzidine, then
23.0 g (80 mmol) of 3,4,3',4'-biphenyltetracarboxylic
dianhydride were added, followed by 100 g of NMP and 10 g
of toluene.

The flask was stirred at 160 rpm for 45 minutes at
15 room temperature, and then reacted in a silicone bath at
180°C for 3 hours at 160 rpm to give a 20% by weight
polyimide solution.

A part of the reaction solution was cast and dried to
give a strong film.

20 Molecular weight measurements by GPC showed M 45,100,
Mn 22,600, Mw 55,800, Mz 104,300, Mw/Mn=2.47, Mz/Mw=4.62.

Thermal analysis was performed. Thermal
decomposition onset temperature T_m was 528°C.

T_g was unknown by DSC analysis.

25

[Example 4]

A polycondensation product was synthesized by the
procedure as described in Example 1.

A flask was charged with 5.46 g (25 mmol) of PMDA, 14.60 g (50 mmol) of 1,3-(bis-aminophenoxy)benzene, 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, 150 g of NMP, and 30 g of toluene.

5 The mixture was reacted at 180°C for 1 hour at 160 rpm, and the reaction solution was allowed to cool for 1 hour, and then 5.01 g (25 mmol) of 3,4'-diaminodiphenyl ether, 5.01 g (25 mmol) of 4,4'-diaminodiphenyl ether, then 22.70 g (75 mmol) of 3,4,3',4'-biphenyltetracarboxylic
10 dianhydride were added, followed by 129 g of NMP and 10 g of toluene. The flask was stirred at room temperature for 35 minutes, and then heated at 175°C for 3 hours and 30 minutes with stirring at 165 rpm. A 15% by weight polyimide solution was produced. A part of the reaction
15 solution was applied on a glass plate and heated at 90°C for 1 hour to give a strong film.

The molecular weight was determined by GPC. The results showed M 42,000, M_n 15,700, M_w 33,500, M_z 46,400, $M_w/M_n = 2.14$, $M_z/M_n = 2.96$.

20 Thermal analysis was performed. Thermal decomposition onset temperature T_m was 534°C, and the temperature at which a 5% weight loss was observed was 544°C. DSC analysis showed glass transition temperatures of $T_g=219^\circ\text{C}$, and 318°C (melt).

25

[Example 5]

A polycondensation product was obtained by the procedure as described in Example 1.

A flask was charged with 5.46 g (25 mmol) of PMDA, 17.43 g (50 mmol) of 9,9-bis (4-aminophenyl)fluorene, 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, then 150 g of NMP and 30 g of toluene. The flask was stirred at room temperature for 1 hour, and heated and stirred under a nitrogen stream. After the mixture was reacted at 180°C for 1 hour at 165rpm, the reaction solution was allowed to cool for 1 hour and then, 5.31 g (25 mmol) of 4,4'-dimethylbenzidine, 14.72 g (50 mmol) of 3,4,3',4'-biphenyltetracarboxylic dianhydride, 78 g of NMP, and 10 g of toluene were added. The flask was stirred at room temperature for 30 minutes. The flask was immersed in an oil bath at 180°C for 10 minutes to completely dissolve insoluble materials. After stirring for 30 minutes, the flask was heated at 175°C for 3 hours and 15 minutes with stirring at 160 rpm.

A 15 % by weight polyimide solution was produced. The solution was cast and dried to give a pale yellow strong film.

Molecular weight measurements by GPC showed M_w 64,300, M_n 27,200, M_w/M_n 2.51, M_z/M_n 4.46.

Thermal analysis was performed. Thermal decomposition onset temperature T_m was 531°C, and the temperature at which a 5% weight loss was observed was 537°C, while no exact value for T_g could be obtained by DSC analysis.

[Example 6]

A solution of a polycondensation product was obtained by the procedure as described in Example 1.

A flask was charged with 5.46 g (25 mmol) of PMDA, 21.63 g (50 mmol) of bis[4- (3-aminophenoxy)phenyl]sulfone, 5 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, 150 g of NMP, and 30 g of toluene. After stirring at room temperature for 1 hour, the mixture was reacted at 180°C for 1 hour at 160rpm. After the reaction solution was allowed to cool for 1 hour, 16.12 g (50 mmol) 10 of 3,4,3',4'-benzophenonetetracarboxylic dianhydride, 9.16 g (25 mmol) of 2,2-bis[4- (3-amino-4-hydroxyphenyl)]hexafluoropropane, 68 g of NMP, and 10g of toluene were added, and the mixture was stirred for 30 minutes at room temperature. Then, the flask was heated at 15 170°C for 3 hours and 15 minutes with stirring at 165 rpm to give a polyimide solution at a concentration of 19%. This afforded a pale yellow strong film.

Molecular weight measurements by GPC showed M 99,900, Mn 20,500, Mw 223,900, Mz 703,500, Mw/Mn=10.91, Mz/Mn=34.2g.

20 Thermal analysis was performed. Thermal decomposition onset temperature T_m was 531°C, and the temperature at which a 5% weight loss was observed was 430°C. DSC analysis showed glass transition temperatures 229°C, 275-360°C.

25

[Example 7]

A polyimide solution was synthesized by the procedure as described in Example 1.

A flask was charged with 14.72g (50 mmol) of 3,4,3',4'-biphenyltetracarboxylic dianhydride, 3.05g (25 mmol) of diaminotoluene, 1.0g (10 mmol) of γ -valerolactone, 1.6g (20 mmol) of pyridine, 100g of NMP, and 30g of toluene.

5 The flask was stirred at room temperature for 1 hour under a stream of nitrogen gas, and then heated at 180°C for 1 hour with stirring at 170 rpm. After the reaction solution was allowed to cool for 1 hour, 5.01g (25 mmol) of 3,4'-diaminodiphenyl ether, 7.01g (25 mmol) of bis[3-amino-4-

10 hydroxyphenyl]sulfone and 5.46g (25 mmol) of PMDA were added, followed by 34g of NMP and 10g of toluene. After stirring for 30 minutes at room temperature, the flask was heated at 180°C for 2 hours with stirring at 170 rpm to give a polyimide solution at a concentration of 20%. This

15 showed yellow and strong film characteristics.

Molecular weight measurements by GPC showed M 55,800, M_n 23,200, M_w 71,200, M_z 282,300, $M_w/M_n=3.07$ $M_z/M_n=12.19$

Thermal analysis was performed. Thermal decomposition temperatures were $T_m=421^\circ\text{C}$ and $T_m=568^\circ\text{C}$,

20 whereby a 5% weight loss was observed at 403°C.

DSC analysis showed glass transition temperature $T_g=278^\circ\text{C}$.

The IR spectrum showed absorption bands at 1780 cm^{-1} (imide bond), 1720 cm^{-1} (adsorption by CO), and 1645 cm^{-1}

25 (absorption by benzoxazole).

[Example 8]

Image formation by exposure to light:

The polyimide solution in NMP of Example 2 was diluted from 25% by weight to 15% by weight with NMP. To 20g of the solution (polyimide content 3 g) filtered through a membrane filter having a pore size of 1 μm was added 0.6 g of a photoacid generator (an ester of 2,3,4-trihydroxybenzophenone and 1,2-naphthoquinone-2-diazido-5-sulfonic acid) in a dark room to prepare a homogeneous solution. This solution was applied on the surface of a silicon wafer having a diameter of 5 cm by spin coating under the conditions of 5 seconds (stop) - 20 seconds (200 r.p.m.) - 5 seconds (stop) - 30 seconds (1700 r.p.m.) - 5 seconds (stop) followed by heat treatment in an infrared heater at 90°C for 10 minutes (prebaking). The film thickness after prebaking was 4.5 μm . A through-hole and line and space pattern was used as a test pattern (10, 15, 20, ..., 100 μm) for a positive photomask on this photosensitive coating film to expose the film to light from a 2 Kw high-pressure mercury lamp (JP200G available from ORC Manufacturing Company Ltd.) at an exposure dose capable of generating an image .

(a) After exposure at 440 mJ/cm^2 , the coating film was immersed in a mixed solution of 40 g of NMP, 40 g of aminoethanol and 40 g of water (hereinafter referred to as solution Ao) at 35°C for 7 seconds, and then washed with deionized water and dried in an infrared dryer at 90°C for 30 minutes and 180°C for 30 minutes, after which the resolution was observed. The film thickness was 4 μm . A sharp positive image having a line and space dimension of

10 μm was observed.

(b) After exposure at $400\text{mJ}/\text{cm}^2$, the coating film was immersed in a 5% TMAH (tetramethylammonium hydroxide) solution at room temperature for 10 seconds and washed with
5 deionized water, and then dried at 90°C for 30 minutes, then 180°C for 30 minutes to give a sharp positive image having a line and space dimension of $10\text{ }\mu\text{m}$.

[Example 9]

10 Positive images were formed by the procedure as described in Example 8.

A mixture of 20 g of the polyimide solution (20% by weight) of Example 6 and 2 g of anisole was filtered through a membrane filter having a pore size of $1\text{ }\mu\text{m}$. To
15 this solution was added 0.2 g of a photoacid generator (an ester of 2,3,4-trihydroxybenzophenone and 1,2-naphthoquinone-2-diazido-5-sulfonic acid) in a dark room to prepare a homogeneous solution. This solution was spin coated on a silicon wafer to form a coating, which was then
20 heat treated at 90°C for 10 minutes to give a film of $5.33\text{ }\mu\text{m}$.

(a) After exposure at $350\text{mJ}/\text{cm}^2$, the coating film was immersed in solution A₀ for 10 seconds and washed with water, and then dried at 90°C for 30 minutes, then 180°C for
25 30 minutes. The film thickness was $3.56\text{ }\mu\text{m}$. A sharp positive image having a line and space dimension of $10\text{ }\mu\text{m}$ was observed.

(b) After exposure at $350\text{mJ}/\text{cm}^2$, the coating film was

immersed in a 5% TMAH solution for 15 seconds, and then dried at 90°C for 30 minutes, then 180°C for 30 minutes to give a film of 3.57 μm . A sharp positive image having a line and space dimension of 10 μm was observed.

5

[Example 10]

Positive images were formed by the procedure as described in Example 8. The polyimide solution of Example 7 (20% by weight) was diluted to 15% by weight with NMP. In 10 20g of this solution was dissolved 0.6 g of 1,2-naphthoquinone-2-diamide-5-sulfonic acid ester of 2,3,4-trihydroxybenzophenone. This solution was spin-coated on a silicon wafer (5 cm diameter). [spin-coating conditions: 5 seconds (stop) - 20 seconds (200 r.p.m.) - 5 seconds (stop) 15 - 30 seconds (3000 r.p.m.) - 5 seconds (stop)]. The coating was heated at 90°C for 10 minutes to form a film of 5.07 μm .

(a) After exposure at 500mJ/cm², the exposed film was immersed in solution A₀ for 1 minute and then washed with 20 water, and then dried at 90°C for 30 minutes, then 180°C for 3 minutes. A sharp positive image having a line and space dimension of 10 μm was observed on this film.

(b) After exposure at 500mJ/cm², the film was immersed in a 5% TMAH solution for 3 minutes. The film was 25 washed with water, and then dried by heating at 90°C for 30 minutes and 180°C for 30 minutes. A sharp positive image having a line and space dimension of 10 μm was observed.

[Example 11]

A 3-neck separable glass flask fitted with a stainless steel anchor stirrer was connected to a condenser tube equipped with balls and a water trap. The flask was
5 heated in a silicone oil bath and stirred under a stream of nitrogen gas.

The flask was charged with 10.91 g (50 mmol) of pyromellitic dianhydride (hereinafter referred to as PMDA), 9.17 g (25 mmol) of 2,4-diaminotoluene (hereinafter
10 referred to as DAT), 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, 100 g of N-methylpyrrolidone (hereinafter referred to as NMP), and 30 g toluene. After stirring at 160 r.p.m for 1 hour at room temperature, the flask was heated at 180°C for 1 hour with stirring at 156
15 r.p.m. A 15 ml toluene-water fraction was removed. After the flask was allowed to cool for 1 hour with stirring, 16.12 g of 3,4,3',4'-benzophenonetetracarboxylic dianhydride (hereinafter referred to as BTDA) and 5.31 g (25 mmol) of 3,3'-dimethylbenzidine were added, followed by
20 90 g of NMP and 10 g of toluene, and the mixture was stirred for 30 minutes at room temperature, and then heated at 180°C for 2 hours and 30 minutes with stirring at 156 r.p.m. to give a 20% by weight polyimide solution.

A part of the reaction solution was cast on a glass
25 plate and heated in an infrared oven at 90°C for 1 hour and 180°C for 1 hour to give a yellowish brown film.

A part of the solution was diluted with dimethylformamide and the molecular weight and molecular

weight distribution were determined by high speed liquid chromatography (available from Tosoh Corporation).

The molecular weight measurements based on polystyrene standards showed peak molecular weight (M)
5 34.200, number average molecular weight (Mn) 15.800, weight average molecular weight (Mw) 57.000, Z average molecular weight (Mz) 259.000, Mw/Mn = 3.60, Mz/Mn = 16.38.

Thermal analysis was performed using a thermal analyzer TGA-50 and a differential scanning calorimeter
10 (DSC) available from Shimadzu Corporation. Thermal decomposition onset temperature T_m was 509°C. Glass transition temperature T_g was not specified by DSC analysis.

15 [Example 12]

A solution of a polycondensation product was obtained by the procedure as described in Example 11.

A 3-neck glass flask was charged with 5.40 g (25 mmol) of PMDA, 6.11 g (50 mmol) of DAT, 1.0 g (1.0 mmol) of
20 γ -valerolactone, 1.6 g (20 mmol) of pyridine, 100 g of NMP, and 30 g of toluene in the same manner as in Example 1.

After stirring at 160 r.p.m. for 1 hour at room temperature, the flask was heated in a silicone oil bath at 180°C for 1 hour with stirring at 160 r.p.m. The flask was
25 allowed to cool and stirred at 150 r.p.m. A 20 g toluene-water fraction was removed. While slowly stirring at room temperature, powders of 3.81 g (25 mmol) of 3,5-diaminobenzoic acid and 10.82 g (25 mmol) of bis[4- (3-

aminophenoxy)phenyl]sulfone were added, followed by 24.17 g (75 mmol) of BTDA. Further, 150 g of NMP and 10 g of toluene were added. After stirring at 160 r.p.m. for 1 hour at room temperature, the flask was heated at 180°C for 4 hours with stirring at 160 r.p.m. to give a solution containing 20% by weight of a polyimide.

Molecular weight measurements by GPC based on polystyrene standards showed M 48.400, Mn 20.000, Mw 99.600, Mz 310.700, Mw/Mn=4.97, Mz/Mn=15.51.

Thermal analysis was performed. Thermal decomposition onset temperature Tm was 525°C, and the temperature at which a 5% weight loss was observed was 325°C.

Glass transition temperature Tg was not specified by DSC analysis.

[Example 13]

The procedure of Example 11 was repeated.

A flask was charged with 10.91 g (50 mmol) of PMDA, 9.17 g (75 mmol) of DAT, 1.0 g (10 mmol) of γ -valerolactone, 1.6 g (20 mmol) of pyridine, and then 100 g of NMP and 30 g of toluene. After stirring at 150 r.p.m. for 1 hour at room temperature, the flask was heated at 165°C for 1 hour with stirring at 180 r.p.m. A 20ml toluene-water fraction was removed. The flask was allowed to cool and then stirred for 30 minutes to 150 r.p.m, and 5.01 g (25 mmol) of 3,4'-diaminophenyl ether and 10.27 g (25 mmol) of 2,2-bis[4-(4-aminophenoxy)phenyl]propane were added, followed

by 24.17 g (75 mmol) of BTDA, 124 g of NMP, and 10 g of toluene. The flask was stirred at room temperature for 30 minutes, and heated at 165°C for 5 hours with stirring at 180 r.p.m. A 20% by weight polyimide solution was obtained.

5 Molecular weight measurements by GPC showed M 52.000, Mn 22.000, Mw 81.200, Mz 211.000, Mw/Mn=3.69, Mz/Mn=9.57.

 Thermal analysis was performed. Thermal decomposition onset temperature Tm was 484°C, and the temperature at which a 5% weight loss was observed was
10 478°C.

 Glass transition temperature Tg by DSC was 302°C.

[Example 14]

 A 18% by weight polyimide solution was obtained by
15 the procedure as described in Example 11.

 A flask was charged with 32.23 g (100 mmol) of BTDA, 6.11 g (50 mmol) of DAT, 1.5 g (15 mmol) of valerolactone, 3.2 g (30 mmol) of pyridine, 140 g of NMP and 30 g of toluene, and stirred at room temperature for 1 hour, and
20 then heated at 180°C for 1 hour with stirring at 160 r.p.m. The flask was stirred at room temperature for 30 minutes, and 6.11 g (50 mmol) of DAT and 10.01 g (50 mmol) of 3,4'-diaminodiphenyl ether were added, followed by 10.91 g (50 mmol) of PMDA, 150 g of NMP, and 10 g of toluene. After
25 stirring at room temperature for 1 hour, the flask was heated at 180°C for 1 hour and 30 minutes with stirring at 160 r.p.m.

 Molecular weight measurements by GPC showed M 32.000,

Mn 13.800, Mw 86.400, Mz 57.800, Mw/Mn=6.27, Mz/Mn=41.9.

The film characteristics were slightly inferior because of the short reaction period of 1 hour and 30 minutes. Thus, heating for 3 hours or more is required to
5 make a strong film.

[Example 15]

A 20% by weight block polyimide solution was obtained by the procedure as described in Example 11.

10 A flask was charged with 16.12 g (50 mmol) of BTDA, 10.82 g (25 mmol) of bis[4- (3-aminophenoxy)phenyl]sulfone, 1.0 g (10 mmol) of valerolactone, 1.6 g (20 mmol) of pyridine, 100 g of NMP, and 30 g of toluene, and stirred at 150 r.p.m for 30 minutes at room temperature. Then, the
15 flask was heated at 175°C for 1 hour with stirring at 160 r.p.m. The flask was allowed to cool and then stirred for 30 minutes, and 9.17 g (75 mmol) of DAT, then 10.91 g (50 mmol) of PMDA, and then 74 g of NMP and 10 g of toluene were added while stirring at 130 r.p.m. After stirring for
20 1 hour at room temperature, the flask was heated at 180°C for 2 hours and 30 minutes with stirring at 155 r.p.m.

Molecular weight measurements by GPC showed M 39.300, Mn 18.700, Mw 86.200, Mz 352.000, Mw/Mn=4.62, Mz/Mn=19.1.

Thermal analysis was performed. The thermal
25 decomposition onset temperature was 506°C.

Tg by DSC was not definite.

[Example 16]

The procedure of Example 11 was repeated.

A flask was charged with 16.12 g (50 mmol) of BTDA,
10.27 g (25 mmol) of 2,2-bis[4- (4-
aminophenoxy)phenyl]propane, 1.0 g (10 mmol) of
5 valerolactone, 1.6 g (20 mmol) of pyridine, 100 g of NMP,
and 30 g of toluene, and stirred at 155 r.p.m for 1 hour at
room temperature to dissolve the materials. Then, the
flask was heated at 175°C for 1 hour with stirring at 155
r.p.m, and stirred at room temperature for 30 minutes.
10 While stirring (120 r.p.m), 3.06 g (25 mmol) of DAT and
5.01 g (25 mmol) of 3,4'-diaminodiphenyl ether were added,
followed by 5.46 g (25 mmol) of PMDA, 115 g of NMP and 10 g
of toluene. After stirring at room temperature for 30
minutes to dissolve the materials, the flask was heated at
15 175°C for 4 hours with stirring at 155 r.p.m. This
polyimide solution was 17% by weight. A part of this
solution was cast on a glass plate and heated at 90°C for
1 hour and 180°C for 1 hour to give a strong film.

Molecular weight measurements by GPC showed M45.100,
20 Mn19.100, Mw128.100, Mz579.000, Mw/Mn=6.70, Mz/Mn=30.3.

Glass transition temperature Tg by DSC was 223°C.

ADVANTAGES OF THE INVENTION

Polyimides containing PMDA are normally solvent-
25 insoluble.

When PMDA (1 mole) is reacted with a certain type of
diamine (2-1.5 moles), an oligomer solubilized at 15% by
weight in solution is obtained. On the basis of this

result, four-component or higher solvent-soluble polyimide block copolymers can be obtained by sequential polymerization reactions using binary acid catalysts. A number of solvent-soluble polyimides containing PMDA are synthesized. Condensation products of an aromatic diamine having an amino group and a phenol group in the ortho positions with a tetracarboxylic dianhydride are useful as positive photoresists. Such compounds are condensation products having benzoxazole groups and polyimide groups in their molecules, rather than polyimides.